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Incentive based Allocation of Terminals in Heterogeneous Access Networks

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Abstract: The contribution of this paper is a solution to the problem of allocating terminals to the appropriate access network in locations where an operator owns multiple access networks with overlapping coverage. This problem is destined to arise since the 3GPP Evolved Packet Core (EPC) allows operators to efficiently manage multiple access networks under one core network. The underlying assumption of this work is that user preferences, terminals, services and access networks are heterogeneous. While in state-of-the-art methods the network decides which terminal goes to which access network, we propose that this decision is taken at the terminal. The essence of our mechanism is that the network gives the terminals an incentive to hand over from an access network if the operator wants them to do so. The network offers the terminal a reward in form of loyalty program points, free minutes, money, or something alike for a handover. The terminal then decides whether to hand over based on the potential reward and other parameters. We further develop a highly configurable framework which allows a vast amount of terminal allocation methods, including incentive based ones. This is achieved by adopting a terminal-centric network paradigm, i.e., all actions are initiated by the terminals but need to be authorized by the network.

Keywords: 3GPP, Cellular networks, Handover, Evolved Packet Core (EPC)

1 Introduction

As the mobile world and Internet world converge, the demand for Quality of Service (QoS) intensive services on mobile devices is increasing. This drives the development of new terminals and new access technologies. However, many of the old access systems and also terminals remain in place. The consequence is that heterogeneity is omnipresent in the mobile Internet. Terminals are heterogeneous with regard to their capabilities. Access systems are heterogeneous with regard to their admission control and QoS provisioning mechanisms. Services are heterogeneous with regard to their QoS requirements. Last but not least, users are heterogeneous with respect to their expectations from the network.

It is foreseeable that the common case will be single operators owning a multitude of access systems, e.g., GSM, UMTS, LTE, WiMAX, WLAN hot spots, etc. In many cases, an operator will own several access networks in a single location. The common case will also be multi-mode terminals, i.e., ones that can connect to multiple - but not always all - access systems.

Therefore, the operators are faced with a new challenge: Allocating heterogeneous terminals appropriately across heterogeneous access networks. Terminal allocation here means that it needs to be decided which terminals go to which access networks. This is often referred as Heterogeneous Access Management (HAM) [SXW+06]. In this paper we propose a mechanism to meet this challenge.

The ultimate goal of the mechanism proposed in this paper is to give an operator the means to distribute user terminals across a multitude of access networks. An example for the necessity of such a distribution is to prevent overload and rejection of users in one of the access networks while another access network in the same location could accommodate more users. In such a situation it is difficult for the network to know which terminals have the capability and are in coverage to hand over. The terminal on the other hand, knowing what capabilities it has, the service it is running and what QoS it can expect in the different access networks, is well-suited to take this decision.

Inter-system handovers, which are the enabler for terminal allocation across multiple access networks, have been standardized by the Third Generation Partnership Project (3GPP). Further, the Evolved Packet Core (EPC) allows the administration of 3GPP accesses and non-3GPP accesses under one core network [3GP]. While 3GPP has also specified the Access Network Discovery Support Function (ANDSF) that deals with static terminal allocation, dynamic terminal allocation across multiple access networks is not (yet) within the scope of 3GPP. A prototype implementation of the EPC is developed in the OpenEPC project [Ope]. Another standard that enables inter-system handover is IEEE 802.21 [TOF+09].

The state-of-the-art of HAM are centralized HAM servers, i.e., entities which collect relevant information from the terminals and decide which terminal goes to which access network. This is known as Multiple Radio Resource Management (MRRM) and is described in the work by Siebert et al. [SXW+06]. A mathematical analysis of HAM is given in the work by Blau et al. [BWKS07]. Schotten and his group address the problem of HAM by utilizing user and network context [MKSS09] and extend this approach to multi-homing [CMK+10]. However, in that work the focus is on the context aspect.

Our approach is to tackle this problem with a terminal-centric network paradigm. In this paradigm, the terminal initiates the communication based on the services run, the available QoS at the different access networks and the desires of the user. The network remains in control of granting or denying access.

The main contribution of this work is a novel mechanism for terminal allocation across multiple access networks. We shift away from the state-of-the-art paradigm of the network ordering the terminals which access network to connect to. Instead, we propose a ”soft” method. The network offers the terminals a reward to hand over, i.e., it gives them an incentive. The reward is in form of loyalty program points, money, free minutes or something alike. The terminals then decide based on a set of parameters whether to initiate a hand over. These parameters not only include the potential reward, but also other parameters such as the available QoS in other access networks. However, the network keeps control in the sense that access can be denied to terminals regardless of this mechanism. We also provide a framework which allows a vast amount of terminal allocation mechanisms.

The concept of incentives in resource allocation in wireless networks has been studied before, e.g., in the work by Liao et al. [LWC03]. However, the issue there is to give users incentives to cooperate in a cell by using certain service classes. Incentive based approaches are very prominent in the context of Peer-to-peer (P2P) networks, which depend on users making their content available to others. A recent example for this is the work by Sirivianos et al. [SYJ09]. Further, incentive mechanisms have been applied to motivate nodes in mobile ad hoc networks to cooperate [ZCY03]. To our knowledge, no work exists on using incentives for inter-system terminal allocation.

The remainder of this paper is organized as follows. In Section 2 we specify the system model. The basic principle of the incentive mechanism is described in Section 3. Section 4 explains how the decision is made in the terminal and presents a framework which allows a vast variety of terminal allocation methods. We conclude in Section 5.

2 System Model

We assume that there is one operator who controls several access networks of different technologies in the same location. In particular, there are cells of different access networks which have overlapping coverage.

These access networks are populated by terminals which are consuming a plethora of services. These services are heterogeneous in terms of QoS requirements. The terminals are within coverage of one or more access networks. Some terminals are multi-mode, i.e., they are capable of connecting to different access networks. Here it needs to be distinguished between terminals which can only connect to one access network at a time and those which can distribute their flows over different access network. The capabilities of the terminals and their coverage situation with regard to other access networks are not known to the network.

The cost for the user for a connection may or may not differ for the different access networks. The billing is time-based, volume-based or a flat-rate. The reaction to QoS degradation may be different for each user.

A typical scenario is depicted in Figure 1. There are three access networks ”A”,”B”, and ”C”. There are areas where only one access network has coverage, there are areas where two access networks overlap and also an area where all three access networks overlap. There are several terminals and it is indicated which access network they are connected to. The access network ”A” can not accommodate more users. Hence, the terminal labeled ”0”, which is only within coverage of access network ”A”, can not connect. However, there are terminals connected to access network ”A”, e.g., the one marked ”A+”, which have the capability and are within coverage to hand over to the access network ”B” which has room for more users. The subject of this work is a terminal allocation mechanism for such scenarios.

Another aspect of the system model is the execution of handovers. We adopt a terminal-centric network paradigm. The terminal checks which access networks are available and what QoS they offer before initiating the connection establishment. Handovers are also initiated by the terminal. The network has the role of authorizing all actions of the terminal at the initial attach as well as

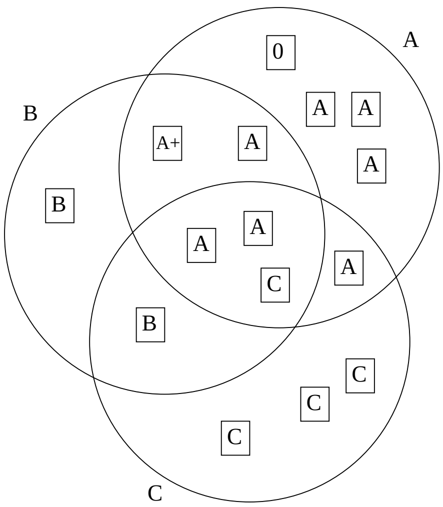

Figure 1: System model

during handovers.

3 Incentive Based Terminal Allocation

3.1 Rationale

The players in the terminal allocation problem are the operator, who owns several access networks, and the terminals. They have different, but not necessarily conflicting goals and different knowledge. The goal of the operator is to ensure efficient usage of its access networks, while the goal of the terminals is to maximize the user experience. What user experience means is defined by each user individually and not known to the network. The operator knows the state of the access networks, but not the capabilities and desires of the terminals. The terminals, on the other hand, know what capabilities they have and what the user wants to do, but have no knowledge about the state of the access networks. In order to perform terminal allocation, one side has to get the missing information from the other one and take the decision which terminal goes to which access network. In this work we explore mechanisms where the state of the access networks is conveyed by them to the terminals, who take the decision which access network they connect to.

The essence of our proposed mechanism is that the network gives the terminals an incentive to hand over from an access network. The incentive is given in form of a reward which is paid to the users who hand over. The reward is in form of loyalty program points, money, free minutes or something alike. The terminal then decides whether to hand over based on the potential reward and other parameters, such as the service consumed and the available QoS at other access networks. If decided to hand over, the terminal initiates the handover. The network reserves the right to reject the handover. This mechanism is a shift in paradigm compared to the state-of-the-art where the network orders which terminal goes to which access network.

Employing this mechanism gives the operator means to balance the terminals in its access

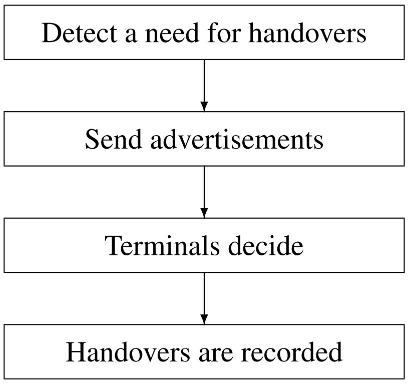

Figure 2: Steps of the incentive mechanism

networks such that the user experience is optimized for many users.

In the following, the procedure is described step-by-step. The steps are depicted in Figure 2. Along with the steps the upgrades to existing infrastructure to deploy this mechanism are presented.

3.2 Step-by-step Procedure

1. Detect a need for handovers. The proposed mechanism is intended as a reaction to a network being in a state where it desires some terminals to move from one access network to another, i.e., detects a need for handovers. An obvious state where this is desired is one access network being overloaded while others are not. There might be also other reasons why an operator wants to move terminals from one access network to another, therefore it is important that the mechanism works regardless of the load level of an access network and it is left to the operator to decide which states are deemed as having a need for handovers. The functionality of detecting a need for handovers has to be implemented in the access networks. Since there is no additional interaction between network entities as well as no interaction between access networks, no new standardization effort is required.

2. Send advertisements. Upon detecting a need for handovers, the network sends advertisements reflecting the current situation to all its attached terminals. These advertisements can be either broadcasted to all or multicasted to a subset of users. The advertisement can contain a direct offer, i.e., the reward that the user will get for handing over. Alternatively, the network state is advertised which is evaluated along with other parameters at the terminal, which then decides whether to handover. The option of advertising the network state by broadcast to all terminals is assumed in the remainder of this paper. Existing and future access networks need to be enhanced with a message from the network to the terminal which conveys the network state. However, it is not required that this is the same message for different access networks. A possible solution is to send the advertisements as IP packets.

3. Terminals decide. Confronted with an offer it is up to the user or terminal to decide whether to stay in the current access network or handover. It is not required that all flows of the terminal hand over, instead this can be done on a per-flow basis, if supported by the terminal and network. There are two ways this can be done. The first way is to query the user with an interactive dialog box. While the appeal of this method is that it incorporates the current mood of the user, its drawback is that it takes seconds, or maybe even minutes before the handover takes place, which might hinder efficient terminal allocation. The second way is to let the terminal decide based on a pre-configured function, which is the method assumed in the remainder of this paper. This step is elaborated in Section 4. The decision which access network to hand over to is dependent on the available QoS at the target access networks, as the desired service needs to be supported with a QoS comparable to that in the source access network. Hence, it is useful if this is one of parameters in the decision whether to handover. It is important to point out that it is not intended to alter the authorization and handover procedures of the access networks. Therefore, regardless of this mechanism the operator reserves the right to remove a terminal from an access network or deny access at will, if this is supported by the access network.

4. Handovers are recorded. There are several ways do administer the delivery of rewards to the terminal without adding much complexity. An electronic token can be sent to the terminal after the handover which the user can redeem later. Further, since handovers are often anyway tracked, the operator can evaluate the list of handovers of each terminal at the end of the month and count the rewardable ones.

4 Handover Decision Mechanism in the Terminal

4.1 Principle

In this section we elaborate on the decision of a terminal to accept an offer to hand over according to a pre-configured function. We show how a generic framework allowing a vast amount of terminal allocation methods ranging from pure network control to anarchic user control can be implemented.

The decision whether to hand over is taken at the terminal and based on the user and operator preferences as well as the context. By ”context” we mean the circumstances at the time of the handover, e.g., the state of the access networks. The parameters also include the potential reward that a terminal will get for a handover. The parameters are weighted and are the input to a function which computes a value. Depending on this value a handover may be initiated. To describe this formally, let x_i be any parameter, w_i be its weight, $\mathbf{f}()$ a function, and D the computed value. Then,

$$D = \mathbf{f}(w_1x_1, w_2x_2, \ldots, w_ix_i). \quad (1)$$

There are two methods how the value D can be translated to a handover decision. The decision can be done deterministically by comparing the value D to a threshold D_t and executing the handover if

$$D > D_t. \quad (2)$$

Alternatively, the handover decision can be done statistically. The evaluation function is constructed such that D takes a value between 0 and 1. Then an uniformly distributed random number D_r between 0 and 1 is generated and the handover is executed if

$$D > D_r. \tag{3}$$

Now let us take a closer look at the parameters. We distinguish three types of parameters: user parameters, operator parameters and context parameters. The context parameters capture the state of the terminal at the time of the potential handover. A key context parameter is the state of the network, which is conveyed to the terminal by a message from the network. Another important context parameter is the available QoS in the other access networks. Further context parameters can be the battery state of the terminal, the number of rewardable handovers done in the past and the current services that the terminal is consuming.

The operator parameters provide means for the operator to control the network. The most important operator parameter is the table of potential rewards. This is a look-up table from which the potential reward is retrieved in conjunction with the context parameter reflecting the state of the network. Other operator parameters can be the subscription type and a cheater indication. The subscription type gives the operator a handle to treat different users differently. The cheater indication is a parameter with which the operator can impede users assumed to be cheating.

The user parameters reflect the preferences of the user. A typical user parameter is the willingness to hand over. With this the user can indicate whether he is open to hand over which maximizes the reward, or whether he prefers to avoid handovers. Generally, it is desirable to keep the number of user parameters low to prevent burdening the users However, an arbitrary number of parameters can be introduced to make the decision dependent on several aspects of the user, e.g., which service is being consumed.

The user and operator parameters are configured statically. The user parameters are set by the user. The operator parameters are conveyed to the terminal via configuration messages sent beforehand. The context parameters are retrieved by measurements. An exception is the parameter reflecting the state of the network, which is advertised by the network. Beyond this message containing the state of the network, no additional HAM specific signaling between the network and the terminal is required when a need for handovers is detected.

The format of the parameters varies. Some parameters are in form of a numeric value. There might also be user parameters with linguistic values. As pointed out above, there are parameters which are in form of a look-up table which yield a numeric value in conjunction with another parameter. In the example in the next section such a look-up is described.

The function computing the handover value must be able to deal with these different kinds of parameters. A straightforward method to ensure this is to map all parameters to numeric values.

The evaluation function can be cascaded, i.e., first certain parameters are evaluated and only depending on the outcome the computation is continued. Formally, this means that when there are two levels

$$D = \mathbf{f}(w_1x_1, w_2x_2, \ldots, w_ix_i, d_1), \tag{4}$$

where

$$d_1 = \mathbf{f_1}(w_{i+1}x_{i+1}, w_{i+2}x_{i+2}, \ldots, w_jx_j). \tag{5}$$

This is useful due to the high battery consumption when retrieving certain parameters, such as the available QoS in other access networks. In such a case the retrieval can be avoided, if it is

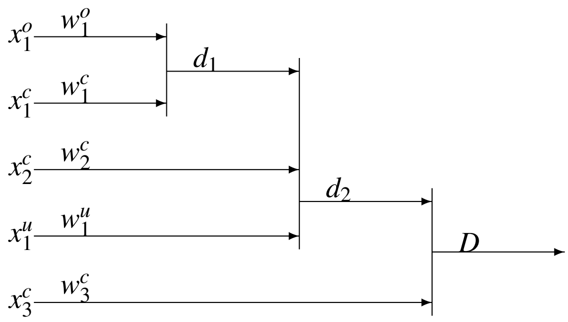

Figure 3: Example of evaluation

already clear from evaluating other parameters that this terminal will not hand over. Cascading the evaluation is elaborated in the following example.

In principle, this mechanism is not limited to handover decisions, but can also be applied to deciding which access network to go to before a service starts.

4.2 Example

An example of the evaluation of the parameters is given below. The user, operator and context parameters are denoted by x_i^u, x_i^o and x_i^c, respectively.

There are five parameters which take values in the interval $[0,1]$. Each parameter has a weight, whose value is also in the interval $[0,1]$.
x_1^o: Look-up table containing potential reward
x_1^c: Network state
x_1^u: User preference between reward and avoiding handovers
x_2^c: Battery state of terminal
x_3^c: Available QoS at other access networks

In this example, the function $\mathbf{f}_1()$ is a table look-up and $\mathbf{f}_2()$ and $\mathbf{f}_3()$ are sums. Further we assume, that there is a threshold D_t and if $D > D_t$ a handover is executed. The evaluation is cascaded using three functions $\mathbf{f}_1()$,$\mathbf{f}_2()$ and $\mathbf{f}_3()$. In the first step, the potential reward for the user is computed.

$$d_1 = \mathbf{f}_1(w_1^o x_1^o, w_1^c x_1^c). \tag{6}$$

From the potential reward table x_1^o the value corresponding to the network state x_1^c is retrieved. A possible table is shown in Table 1. There the parameter x_1^c can take an integer value between 0 and 4. It is important to note that the result d_1 is not the potential reward in the unit of a currency, loyalty program points or free minutes, but a weighted numeric value which serves as input for $\mathbf{f}_2()$. Together with the parameters reflecting the battery state and the user preference, the value

Network state x_1^c	Value d_1
0	0
1	$w_1^c \cdot w_1^o \cdot 0.3$
2	$w_1^c \cdot w_1^o \cdot 0.6$
3	$w_1^c \cdot w_1^o \cdot 0.8$
4	$w_1^c \cdot w_1^o \cdot 0.9$

Table 1: Parameter in form of a look-up table

d_2 is computed.

$$d_2 = \mathbf{f}_2(d_2, w_1^u x_1^u, w_2^c x_2^c) = d_1 + w_1^u x_1^u + w_2^c x_2^c. \tag{7}$$

At this point all parameters other than the one reflecting the available QoS in other access networks have been evaluated. If it could already be concluded that this terminal will not hand over, or will definitely handover, the battery consuming retrieval of the last parameter could be spared. A simple test is to check whether the threshold can not be reached or is definitely reached if the parameter reflecting the available QoS in other access networks takes one of the extreme values, which is the case when $w_3^c x_3^c = 1$ or $w_3^c x_3^c = 0$. I.e., it is checked whether

$$d_2 + w_3^c \cdot 1 < D_t, \tag{8}$$

and whether

$$d_2 + w_3^c \cdot 0 = d_2 > D_t, \tag{9}$$

If Inequalities (8) or (9) hold true, the procedure can be ended here. In the case of Inequality (8) holding true, no handover is executed, in case Inequality (9) holds true, a handover is executed. Otherwise, the value D is computed.

$$D = \mathbf{f}_3(d_2, w_3^c x_3^c) = d_2 + w_3^c x_3^c. \tag{10}$$

Finally, it is checked whether $D > D_t$. If this is the case, a handover is executed, otherwise the terminal stays in the current access network.

4.3 Relationship to other Terminal Allocation Mechanisms

It can be seen that by choosing the parameters which are used for the computation and adjusting their weights, the operator can configure a wide variety of terminal allocation mechanisms. By setting the weight of the user parameters to 0 and not providing incentives a purely network controlled mechanism is implemented. On the other hand, by setting all weights but the user parameters to 0, an ”anarchic” method where the users do what they want is implemented. In other words, setting the weights constitutes a ”turning knob” for operators with which they can configure the desired terminal allocation mechanism.

5 Conclusion

In this paper we address the problem of terminal allocation across multiple access networks that will be common for operators in the future. The main contribution of this work is the incentive based terminal allocation mechanism. The operator leaves the decision which access network to connect to the terminals but gives incentive, e.g., in the form of loyalty program points, money or free minutes, to the users or other information to the terminals to incorporate the operator's interests. We further develop a framework which can be configured to implement a vast amount of terminal allocation methods. The terminal decides based on user, operator and context parameters, which may or may not also contain an incentive to hand over.

This mechanism has several advantages. It allows scalability in the sense that new terminals can be easily added to the network. Beyond that, it is not limited to specific access technologies and can be used for future access networks. Heterogeneity with regard to terminals is supported as it is not required that all terminals participate, regardless whether due to lack of multi-mode capability or lack of implemented functionality. Heterogeneity with regard to access networks is supported as the access networks act autonomously and require no additional functionality other than sending advertisements. Heterogeneity with regard to services is supported as it can be prevented that terminals running fragile services hand over. Heterogeneity with regard to users is supported as the users' individual preference can be incorporated while taking the decision. Using incentive based terminal allocation methods adds another aspect to the economic analysis. It also complicates performance studies, as the user behavior needs to be modeled as well. A topic of future work will be the extension to a multi-operator case, which brings up the challenge that it is hard to imagine an operator giving its customer a reward to hand over to the competitor's network. A further topic for future work is a performance analysis of the proposed mechanism.

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Bibliography

[3GP] 3GPP. TS 23.402. Architecture Enhancements for Non-3GPP Accesses. http://www.3gpp.org/ftp/specs/html-info/23402.htm.

[BWKS07] I. Blau, G. Wunder, I. Karla, R. Siegle. Cost based Heterogeneous Access Management in Multi-Service, Multi-System Scenarios. In *Proceedings of the IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC 2007)*. Sept. 2007.

[CMK+10] S. Carrella, C. Mannweiler, A. Klein, J. Schneider, H. D. Schotten. A Concept for Context-aware Multihoming with Heterogeneous Radio Access Technologies . In *Proceedings of the 5th Annual ICST Wireless Internet Conference (WICOM 2010)*. Pp. 1–7. Mar. 2010.

[LWC03] R. Liao, R. Wouhaybi, A. Campbell. Wireless Incentive Engineering. *IEEE Journal on Selected Areas in Communications* 21(10):1764 – 1779, Dec. 2003.

[MKSS09] C. Mannweiler, A. Klein, J. Schneider, H. D. Schotten. Exploiting User and Network Context for Intelligent Radio Network Access. In *International Conference on Ultra Modern Telecommunications & Workshops, 2009. (ICUMT 2009)*. Pp. 1–6. Oct. 2009.

[Ope] OpenEPC - Open Evolved Packet Core. http://www.openepc.net.

[SXW+06] M. Siebert, B. Xu, E. Weis, B. Bayer, D. Sivchenki, T. Banniza, K. Wnstel, S. Wahl, R. Sigle, R. Keller, A. Dekorsy, M. Bauer, M. Soellner, J. Eichinger, C. Gan, F. Pittmann, R. Khne, M. Schlger, I. Baumgart, R. Bless, S. Stefanov. ScaleNet - Converged Networks of the Future. *Information Technology* 48, Oct. 2006.

[SYJ09] M. Sirivianos, X. Yang, S. Jarecki. Robust and Efficient Incentives for Cooperative Content Distribution. *IEEE/ACM Transactions on Networking* 17(6):1766–1779, December 2009.

[TOF+09] K. Taniuchi, Y. Ohba, V. Fajardo, S. Das, M. Tauil, Y.-H. Cheng, A. Dutta, D. Baker, M. Yajnik, D. Famolari. IEEE 802.21: Media independent handover: Features, applicability, and realization. *IEEE Communications Magazine* 47(1):112–120, Jan. 2009.

[ZCY03] S. Zhong, J. Chen, Y. R. Yang. Sprite: A Simple, Cheat-Proof, Credit-Based System for Mobile Ad-Hoc Networks. In *Proceedings of the 22nd Annual Joint Conference of the IEEE Computer and Communications Societies (INFOCOM 2003)*. Pp. 1987–1997. 2003.